STATE & PRIVATE FORESTRY
FOREST HEALTH PROTECTION
SOUTH SIERRA SHARED SERVICE AREA

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To: **Eldorado National Forest, SoFAR collaborative working group**

From: **R5** State and Private Forestry, Forest Health Protection (FHP), South Sierra Shared Service Area

Subject: Common Damage Agents of True Firs: background, biology, and management

Abstract

When all forest health threats to California's native conifers are considered, *Heterobasidion* root rot and dwarf mistletoes (DM) are the top two pathogens in the Southern Sierras. Focusing on red fir trees (*Abies magnifica*) the same two pathogens still top the list. Other biotic agents such as fir engravers or woodborers are most often observed, but rather are secondary agents influenced by prior *Heterobasidion* or DM infections. The underlying interactions of agents along with abiotic stressors, all contribute to eventual mortality of true firs. A survey of the published literature on health of true firs in California, reveal that much more has been published on white fir than on red fir, but the consensus is that conclusions from white fir can largely be applied to red fir until better information is available. Studies of Natural Range of Variation (NRV) indicate that red fir is largely within its historical range. In recent decades there has been a lengthening of fire return interval resulting in an intensification of understory tree density. As a result, mistletoe density increases with host abundance, but its overall distribution has changed little. Reintroducing prescribed fire to reduce fuel loading and to increase stand resilience will kill heavily DM-infected small trees and thus reduce lateral rate of spread of this parasitic plant. When *Heterobasidion* root rot is evaluated, a stark difference between the white and red fir resources becomes apparent. For the first 170 years of California logging, mostly in the pine and white fir, no attempt was made to control this fungus and over the last 30 years there have been many instances where beetle-kill salvage and hazard tree salvage operations did not involve the application of an approved borate stump dressing. Consequently, fir annosus is widespread in white fir forests of Eldorado and Stanislaus National Forests. It would take several entry cycles without a borate stump dressing before the level of *Heterobasidion* infection in the red fir resource would reach the same levels as currently seen in some white fir stands.

NOTE: This document is meant to be a reference guide of the most common insect and diseases encountered in red fir forest types on the Eldorado National Forest and adjacent lands. Land managers and partners can refer to this report when planning or encountering specific pests, then deciding appropriate strategies based on agreed objectives. All alternatives listed in the report cover a range of relevant studies designed to monitor or treat these damage agents. However, eradication is not practical nor is complete suppression feasible as mentioned pests are native or long-established non-natives. Insects and diseases should be weighed if mitigation is necessary due to projected unacceptable effects or loss, rather than removal from the site. FHP can help determine prognoses based on current conditions or other projected changes.

Introduction

Cannon *et al* (2016) "Diseases of Conifers in California", described the *heavy hitters* of the 52 native coniferous species of California. When the host list is reduced from 52 native conifers to only one host species – red fir (*Abies magnifica*), the first and second place threats to forest health remain the same: namely, *Heterobasidion* (a.k.a *Annosus*) root rot and dwarf mistletoes (DM). Both of these agents are native which is significant in any discussion of forest health, because the host (red fir) and the pathogens – dwarf mistletoe or Annosus root rot – have coevolved with complex relationships. In native ecosystems, tree mortality results from complex interactions amongst native insects, native pathogens, stand conditions, drought and or deviations from local climate. Under conditions of local climate, insects can be frequently be found attacking trees that are also infected by native fungi. In times of drought, attacks by fungi and insects can work independently and insects become primary killers of trees (Cobb et al 1974).

In contrast, when host and pest have not coevolved, invasive insects or pathogens have competitive advantage from other diseases or insects and behave as primary killers of trees since there are no adapted predators or other control agents. The Emerald Ash borer (*Agrilus planipennis*) has killed millions of ash trees as it has advanced westwards, unchecked, across the US. (Poland, & McCullough 2006). In a similar manner, the Goldspotted Oak borer (*Agrilus auroguttatus*) is spreading northwards from Southern California (Coleman *et al*, 2017). The most educational example might be White Pine Blister Rust (*Cronartium ribicola*). Unlike the insect examples which were recent introductions, this fungus has been in the West for about 100 years. In that century, the fungus and its sugar pine host have begun to coevolve and some naturally selected genetic resistance to this fungus has developed (Tainter & Baker 1996). A much more recent exotic introduced into California would be Sudden Oak Death (*Phytopthora ramorum*) which was first detected in 1993. Its numerous newly encountered hosts have not had much time to adapt to this pathogen, so resistance is minimal (Rizzo & Garbelotto, 2003).

Fir annosus caused by *Heterobasidion occidentale.*

The most serious threat to managing the red fir forests is fir annosus, caused by *Heterobasidion occidentale*. This disease was initially (still is often) called "S" type of *Fomes annosus*, renamed in 2009 by Otrosina & Garbelotto. In this report, the common name will be fir annosus, formal name as *Heterobasidion occidentale*, and technical name is Heterobasidion Root Disease. While *Heterobasidion occidentale*, *Scolytus ventralis* (fir engraver) and *Armillaria* species are all coevolved native agents in close association with red fir, there are two aspects of active forestry that have the potential to increase threat posed by *H. occidentale*. They are: avoidable logging wounds, and highly treatable freshly cut stumps.

While the biology of *H. occidentale* is well known (Scharpf 1993, Tainter & Baker 1996, Wood et al 2003), much of the knowledge comes from studies of white fir (*Abies concolor*) in the mixed conifer forest type. Generally, insects and diseases of white fir behave in similar manner when red fir is host. While some changes in behavior of the fungus can be expected, they will be generally minor. Most observations in managed red fir are similar to those made in white fir stands (Scharpf 1979). A review of the biology of fir annosus is made to understand its behavior in white fir forest and to outline steps that will have to be taken to prevent red fir stands from deteriorating into unhealthy states.

As earlier stated, fungus and hosts (red or white fir) have coevolved over millennia, and *Heterobasidion* was not a significant cause of mortality in California until after the Gold Rush of 1848 (Cannon *et al*, 2016). Since then millions of people have come to California and their demand for wood led to the first exploitive cutting of forests. For the first 170 years of logging in California, no effort was made to control this disease. Consequently, this disease slowly became more widespread than it had been before the Gold Rush. To better understand this process, *Heterobasidion* fungus spread is first explained (see Figure 1).

Airborne basidiospores are the main means of spread of this fungus and are an important means of long distance spread (Rishbeth 1951). It is where and how these spores are produced that makes this fungus such a significant threat to forest management of red fir. *H. occidentale* is a butt and root rot fungus that will decay the stump of a tree from the inside out (see Figure 1). A fruiting body will be produced in the cavity created which will contain millions of spores for dissemination into the cavity within the stump. Moisture released by the decay process keeps the cavity moist and prevents the spores from desiccating. Eventually the top of the cavity collapses in, as the layers of wood remaining above decay. After the roof of the cavity has collapsed, and air in the cavity has outside access, spores can escape. The morning sun warms air within the cavity and as expanding air rises, released spores will be carried up and out. Some of these spores are passively carried in the wind then deposited upon another freshly cut stump. The spores germinate upon landing and begin to infect another stump. Thus, fresh cut stumps in managed stands will have to be protected from infection by airborne spores of *H. occidentale*.

Working in Finland, Kallio (1970) has produced the most detailed assessment of airborne spread of *Heterobasidion* spores. His paper reports spore spread over distances of 44 to 310 miles. Working in England, Rishbeth (1959) found spores of *Heterobasidion* had been carried over 200 miles of sea. Looking for an American estimate, UC Berkeley professor Matteo Garbelotto obtained an estimate of 1600 ft (500 m). Knowing the majority of spores are deposited close to the initiating conk, Kallio (1970) found that at 200 m (656 ft) from a conk, a 5-minute exposure of a petri dish was adequate to capture this fungus. That Petri dish equates to a 4-inch stump exposed for 5 minutes. A 200 m radius is equivalent to an area of about 31 acres. Which means that every freshly cut unprotected fir stump in the 31 acres surrounding one conk has a credible risk of becoming *Heterobasidion* infected. Using Garbelotto's estimate of 500 m increases the criterion to one conk at the center of about 190 acres of potential infection.

For the first 170 years after the Gold Rush, there was no attempt to control this fungus, and thus it has slowly expanded in native stands. Like all native root diseases this fungus does not years spread fast and it may take several decades before the slow chronic mortality it is causing is noticed. Early logging in California was done to clear the land for cities and agriculture, and root disease prevention was of little consequence. However, this fungus plays a waiting game and it may often take several subsequent entries before impact of earlier decisions become visible. *Heterobasidion occidentale* has been observed fruiting within hollowed out stumps on the Stanislaus and Eldorado National Forests, which were cut over 50 years earlier. In these cases, stumps were hollowed out to the point where very little of the original stump remained and yet the *Heterobasidion* conks were healthy and actively producing spores. This fungus can wait because it has a second means of spread. Namely via root grafts (Figures 1 & 2).

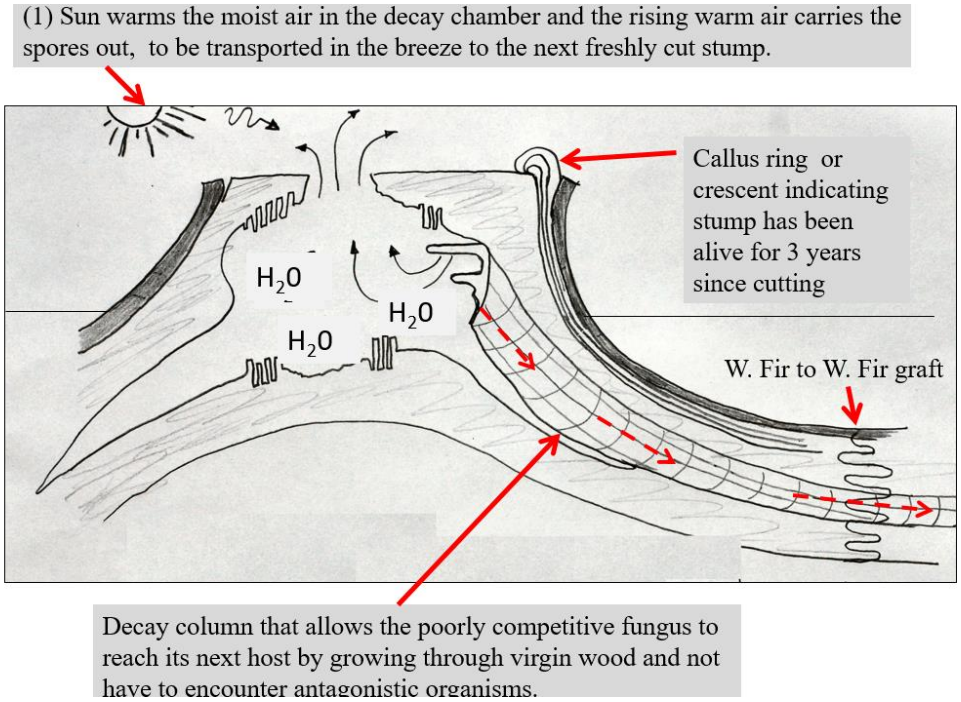

(1) Sun warms the moist air in the decay chamber and the rising warm air carries the spores out, to be transported in the breeze to the next freshly cut stump.
Callus ring or crescent indicating stump has been alive for 3 years since cutting
H20
H20
H20
W. Fir to W. Fir graft
Decay column that allows the poorly competitive fungus to reach its next host by growing through virgin wood and not have to encounter antagonistic organisms.

Figure 1. Cross Sectional diagram of a typical white fir stump in a fir annosus root rot pocket

Once *Heterobasidion* is established in a stand, it is almost impossible to remove. As is shown in Figures 1 & 2 the fungus can grow from one host tree to the next if the trees are root grafted. By growing down a root and into the adjacent tree the fungus does not have to compete with too many other fungi. Inside a root grafted stump the fungus does not run out of food, even after it has almost exhausted all of the nutrients in the stump, for the conks in the stump are being supplied by the fungus at the feeding front, that is decaying the butt of an adjacent fir tree. One way that it might be possible to remove the disease from sections of a red fir stand would be by species conversion. It would be possible, if small mortality pockets are discovered in a red fir stand, to remove the red fir at the edge of the pocket and replant the whole pocket in a conifer such as rust resistant western white, ponderosa, or Jeffrey pines assuming that the pocket is not needed for wildlife considerations. Fir annosus is a natural part of a red fir ecosystem and should not be completely eradicated. However, a slow and unmanageable expansion of the disease that is well beyond its Natural Range of Variation (NVR) is an undesirable condition (Meyer & North, 2019). In the absence of a living susceptible, grafted host, the fungus will eventually die out. This could take 20 to 50 years depending upon the stump size. Once more, pointing out that this fungus has evolved a survival strategy that takes many years (USDA, 2013).

"*Once Heterobasidion is introduced into a stand, it is there forever*." (Professor Matteo Garbelotto, UC Berkeley, *personal communication*). During the reconstruction phase after World War II, this fungus was accidentally introduced into Italy and over 70 years later it is a persistent problem (Gonthier *et al*, 2004). Although this earlier introduction is speculated, the slow spread strategy of this fungus is highlighted by the fact that it was not identified in Italy until 2004. On several occasions on Eldorado and Sequoia National Forests, FHP has observed cases in which fir annosus has slowly driven species conversion from white fir to predominantly incense cedar (species immune to fir annosus). If borate prevention treatments are not implemented in present red fir forests, this disease may encourage slow replacement of red fir with presumably lodgepole pine or create a perpetual state of low vigor for remaining red fir. It has only been in the last 30 years that a borate stump treatment has been available but can still be utilized to prevent undesirable conditions in stands with no or minimal detected root disease.

In order to get a measure of what could happen if stumps in a red fir stand were repeatedly not treated after thinning operations, FHP conducted a brief survey in near Cold Springs, Stanislaus National Forest. The project area was mixed conifer type, with sugar pine dominance. Both incense cedar and white fir were well represented in the canopy, Douglas-fir having only a minor presence. There had been a thinning some time ago (15-20 years) and more recently 2019 there had been a salvage cut of beetle-kills and hazard trees. Callused stumps of white fir were very numerous – in fact 33 out of out of 35 stumps showed callusing indicating that ~94% of white fir stumps were still alive due to root-grafting from adjacent trees. However, by the time of the next entry (i.e. hazard tree salvage) 88% of closest white fir to callused stumps had died. In summary 35 trees had been cut at the thinning entry, but by the time of salvage entry another 29 trees had died and none of them more than 8 ft from a once living stump (Figure 3). Thirty-five trees were cut, but a total of 64 trees had died. The simplest explanation for these observations is to assume that cut surfaces of grafted stumps were the equivalent of logging wounds. If living trees kept the stump alive, that tree was susceptible to infection by the pathogen while the more common saprophytes would be at a disadvantage. The resiliency of the mixed conifer forest type lies in part, in the large number of different species it contains.

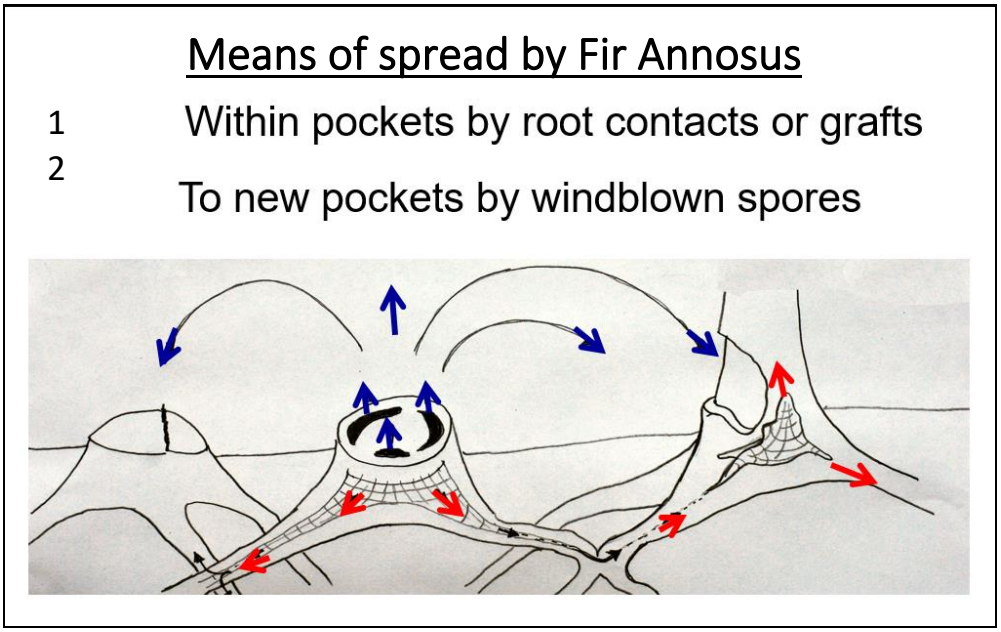
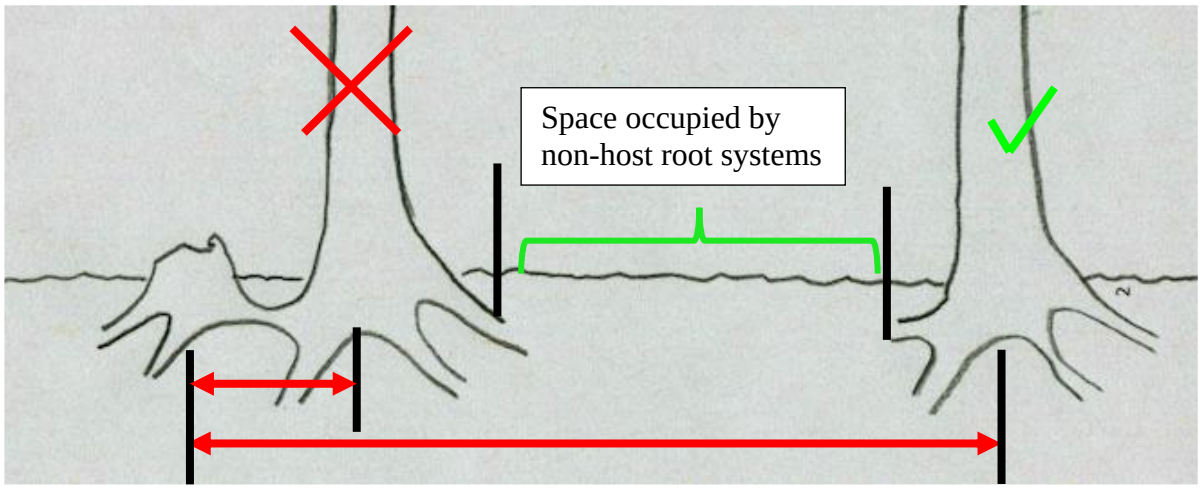


Figure 2. The two means of spread of *Heterobasidion occidentale.*

When one species is in decline, another species will take advantage of the situation and become more dominant. With root rots the species diversity is reflected in the *breaking up* of the below ground landscape of root systems. In the case of the Cold Spring project the root systems of white fir are interspersed amongst the root systems of sugar pine, incense cedar and an occasional hardwood or brush (all of which are immune to fir annosus, (Scharpf 1993). When we begin intensive management of the red fir forest type, we will not have the below ground diversity seen in the mixed conifer forest type, for red fir can in places be a monoculture and thus the potential for spread by root grafting is much higher. When surveying un-managed red fir stands in the Sequoia Kings National Park *Heterobasidion* conks have been found inside the stumps of fir trees that were cut to facilitate the building of roads or the stringing of telephone wires in the National Park. In monitoring US Geological Survey plots a long way from a road we have also found conks in the remains of long dead and

badly decayed red fir. Likewise, conks of *H. occidentale* were found in 3 stumps and 2 dead and snapped snags in the Cold Spring project area.

Grafted stumps do not cause mortality. However, it is suggested that if the stumps are not borate treated, and they happen to be grafted to a close by fir, the stump surface will act, as if it were, as a logging wound and increase the probability of the closest tree subsequently dying. There is another explanation for these observations. While surveying in the Cold Spring project, the occasional remains of stumps which had been dead for many decades were encountered. These dead stumps also showed signs of having once been alive (i.e. grafted). This stand has been thinned several times as noted by numerous stumps of varying decay. Thus, the buildup of fir annosus may have been going on for multiple decades and at the point where almost all the canopy firs are already infected with fir annosus. At this point of infection, stand canopy is most likely on a slow trajectory to convert to sugar pine and incense cedar.



Stump to closest Dead white fir tree.
Average distance 2 ¼ ft
Range 0- 8 ft

Stump to the closest Living white fir tree.
Average distance 32 ft
Range 13 - >50 ft

Figure 3. Depiction of the survey results from the Cold Springs project; where 94% of the stumps were grafted to a once living white fir, and 88% of the closest white fir to a callused stump had died by the time of the next entry.

Multiple observations in California forests have shown that stumps provide a superior habitat for production of *H. occidentale* conks and spores. As current management focuses to better manage red fir resource by increasing resiliency and reducing potential for high severity fires, it essential that all fir stumps be borate-treated to reduce the level of fir annosus stump infections.

In an unpublished report Meinecke reported the 1909 discovery of *Fomes annosus* in California (Smith, 1989). By 1946 it was determined that *F. annosus* was killing trees in California, although the extent of the mortality attributable to this fungus was not fully known (Wagener & Cave, 1946). In Smith's 1989 history of *Heterobasidion annosum*:

> "*In the early 1970's, as many of the true firs (which had been released in the earlier pine high-grading harvests of the mixed conifer and eastside pine types) were approaching commercial*

size, an unexplained crown decline and tree death of pole-sized and larger white fir was observed."

By the 1970's western pathologists were aware that there needed to be a method to control this fungus. At every management entry into the mixed conifer or eastside pine fir annosus was gaining a larger foot hold in white fir stumps. Western forest pathologists were aware of the work by Driver (1963) who had shown that he could control *Fomes annosus* infection of freshly cut pine stumps, by applying a light dressing of borax. In 1970 Graham (1971) found that he could protect both ponderosa and Jeffery pine stumps form *F. Annosus*. Finally in 1970 (Smith, 1970) proved that borax could be used to treat the stumps of white fir. Today a proven cost-efficient means of disease mitigation is available (Graham 1971; Smith 1970). Kleijunas (1989) summarized the existing literature on borax effectiveness.

Schultz *et al* (1992) did compare borate treatments versus no treatment and found that discerning mortality attributable to Fir annosum was difficult. They conducted a long-term study of borax efficacy when applied immediately to recently cut stumps in unthinned stands in California. While they demonstrated that borate application had reduced the rate of infection in stumps, after 10, 11, or 12 years the level of tree mortality of true fir or other species was no different between their treated and the untreated plots. One paragraph in their discussion reads:

"Fir mortality was caused mainly by wind and snow breakage and miscellaneous bark beetles. It was not feasible to determine if any of this mortality was associated with root disease. Small annosus root disease centers of fir mortality were identified in some plots, but they were known to have been there prior to the start of this study. A few trees of other species also died during the study period, but there was no difference between borax and control plots."

If fir mortality was caused mainly by wind and snow breakage it is not surprising that a borate dressing should have had no effect on this type of mortality. However, the authors did advance other explanations that should be given consideration: 1) fungus can linger for years before new symptoms are observed, 2) larger stumps provide suitable long-term habitat for fungus. It might take years for the true impact of the treatments to become obvious – one decade is too short a window to make discernable comparisons between treatments. Several decades passed before foresters recognized the full effect of not applying stump dressings in white fir stands. Goheen and Goheen (1989) found that *Annosus* mortality was observed in 15 to 30-year-old stumps. Further they found that pine annosus mortality was clustered around ponderosa stumps 18 inches or larger, whereas Schultz et al (1992) had stumps that were only <13 inches and 10-12 years old.

Long-term effects of *Heterobasidion* root disease

It must be recognized that large number of red fir and white fir ecotypes in federal, state, and private lands have different silvicultural histories. When commercial forestry began in earnest in California, no effort was made to treat stumps for fir annosus. It has only been in the last 30 years that a borate treatment has been available, and often deployed unevenly. It could be said that for the first 140 years of utilization in fir stands, "no action" option was default. As the FHP survey in the Cold Springs project has shown, this option leads to an intensification of fir annosus to the point that South Sierra foresters have questioned the efficacy of stump treatments at all. In lower elevation stands where there have been 2 or 3 entries over the last 60 years with no application of borate, the disease is considered ubiquitous, so foresters rightfully question the benefit of future stump treatments. In contrast, higher elevation red fir stands have had fewer entries. Often these were no more than fire suppression or removal of beetle- or fire-killed trees along roadsides. Consequentially, current levels of fir annosus in (largely unmanaged) red fir stands is much lower than in white fir and mixed conifer stands (Meyer and North 2019). It is the objective of FHP to assist land managers in reducing hazardous fuels and

increasing red fir stand resiliency without increasing background level of *Heterobasidion* root disease. Considering how the disease has progressed in the white fir stands, "No Action" alternatives would not meet desirable conditions for red fir ecosystems.

Dwarf Mistletoes

In their assessment of the forest health threats to Californian Mediterranean Forest Systems, Cannon *et al* (2016) listed the one two punch for all of California's 25 native conifers as annosus root rot and dwarf mistletoes, the same two major threats to the health of red fir resource. Although, in the second edition of the *The Jepson Manual: Vascular plants of California* (Kuijt 2012) has reduced the number of California species of dwarf mistletoe to only 3. In this report, the alternative taxonomy of Mathiasen & Kenaley (2016) is used to distinctly separate species by acknowledging that there are differences. The dwarf mistletoe that infects red fir is *Arceuthobium abietinum formae speciales magnificae.* The white fir form of the mistletoe is *Arceuthobium abietinum formae speciales concoloris.* The white fir from will not infect the red fir and vice versa. Although white and red firs have a lot in common, they have coevolved with mistletoes long enough for each host species to have its own form of the mistletoe.

Ferrell (1980, 1989) developed a Risk-Rating system for both white and red firs growing in northern California but it is less often used than the 6-class Dwarf Mistletoe Rating (DMR) system of Hawksworth (1977). Applying visually estimated values to the crown for an individual tree the Risk-Rating systems of Ferrell (1980 & 1989) gave a point score that could be translated into the probability of a fir tree dying in the next 5 years (Ferrell 1980) or 10 years (Ferrell 1989). In contrast, the Hawksworth (1977) system focused entirely on the visual characteristics of mistletoe infection of an individual tree's crown. For the Hawksworth (1977) system the live crown of the tree is visually divided into thirds and each third rated as; 0 = no visible infection, 1 = light infection (less than half of the number of branches in the crown third have dwarf mistletoe infections), or 2 = heavy infection (more than half of the number of branches in the crown third have dwarf mistletoe infections). Bole infections are rated as 2. The three ratings are then added to obtain a tree rating. The tree ratings of all live trees (including uninfected ones) are then averaged to obtain a stand or plot rating. Field foresters are frequently issued a business sized card that shows this rating system (see Figure 4).

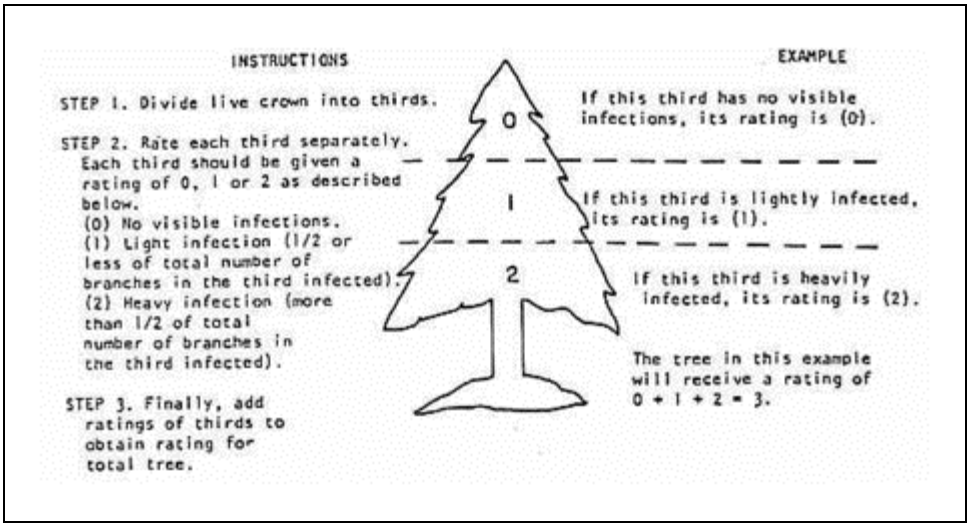

INSTRUCTIONS
STEP 1. Divide live crown into thirds.
STEP 2. Rate each third separately. Each third should be given a rating of 0, 1 or 2 as described below.
(0) No visible infections.
(1) Light infection (1/2 or less of total number of branches in the third infected).
(2) Heavy infection (more than 1/2 of total number of branches in the third infected).
STEP 3. Finally, add ratings of thirds to obtain rating for total tree.
EXAMPLE
0
1
2
If this third has no visible infections, its rating is (0).
If this third is lightly infected, its rating is (1).
If this third is heavily infected, its rating is (2).
The tree in this example will receive a rating of 0 + 1 + 2 = 3.

Figure 4. An enlarged copy of a business card sized description of the DMR system used by field foresters.

Before discussing the use of DMR in management decisions, it would be prudent to review the work of Tinnin *et al* (1982). These authors point out *brooms* (abnormal growth of branches in tight clusters) of lodgepole pine, Douglas-fir, and ponderosa pine are globose and the endophyte system grows synchronously within the broom shoots it induces. In contrast brooms of true firs are not globose but flattened. The dwarf mistletoe plant is divided into two parts. There are the green aerial shoots (the plants as most people think of them). The second part is the roots, this is called the endophytic system. If the shoots of a red fir broom bear plants, it is because of new infections from seeds and not from systemic growth of the endophyte system out of the initial infection site and into the new shoots of the broom. In the brooms of Douglas-fir, lodgepole, or ponderosa mistletoes the new shoots become infected by growth from within. In contrast, brooms of true firs become infected by seeds. The nature of true fir brooms makes them difficult to recognize (i.e. not spherical in shape), and thus the 6-point DMR system may underestimate the level of tree infection in red firs. When a tree climber was put up into mature red fir trees, numerous mistletoe plants were detected that could not be seen from the ground even with field glasses (B. Bulaon *personal communication*)

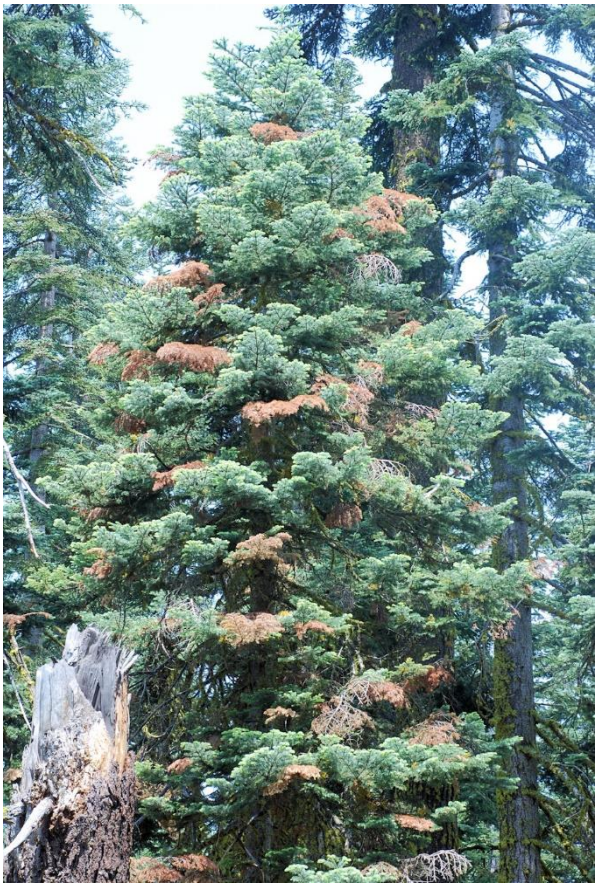


Image 1. A suppressed fir tree, which on closer inspection had numerous mistletoe infections on other green branches. Red-flagged branches, usually attributed to death from *Cytospora abietis* infections, may or may not have been initially induced by mistletoe.

As described by Tinnin *et al* (1982) the absence of globose brooms in true firs makes the DMR system of Hawksworth difficult to apply. However, if *Cytospora*-induced flagging is used as a substitute for brooming, it becomes possible to obtain a *de facto* DMR (Image 1). This *de facto* rating estimates where the mistletoe has been and not where it currently is. Additionally, there is a latent period after germination of 2 to 6 years, before green aerial shoots appear. While Image 5 might look alarming, this tree would only rate a 3 in the *de facto* system. In times of a drought, every flagged branch is dead then consuming no water. In times of drought, heavily flagged branches will have a reduced demand for water. It is still possible that *unseen* aerial plants on green branches will be consuming increased amounts of water. In this way the dwarf mistletoe is a double-edged sword. While totally systemic plants consume little or no water, active green plants are parasitic stealing water from the host. When infected branches are killed by *Cytospora* the water demand by a whole branch is shut down enabling, perhaps, a tree to survive a local drought.

Foresters working in Douglas-fir, ponderosa, or lodgepole pine stands have documented DMR and generated some rules of thumb that can also be applied to red fir (Filip *et al* 2000). In general, a tree's DMR will increase by one class in a decade (Filip *et al* 2000). Further, trees with a DMR of 2 or 3 usually live for another 15 years or longer, and those with a DMR of 5 or 6 frequently don't live for another 15 years. While the DMR is a course filter for silviculture it can be used to prioritize thinning treatments. Thinning selection in true fir, for increasing stand resiliency or reduction of fuels, should be based upon both live crown ratio and the Hawksworth dwarf mistletoe rating. The highest priority for removal should be trees with a live crown ratio < 40% or trees with a live crown ratio of < 60% with a DMR of 5 or 6. The last trees to be removed should those with a live crown ratio > 80% and DMR < 3 (Filip *et al* 2000). Although these recommendations have been published, FHP has found it difficult apply the DMR system to firs such as those shown in Images 1 and 4. FHP would suggest that thinning decisions should be done on a combination of the live crown ratio (i.e. the raggedness percent of Ferrell 1980) and a measure of flagged branches. But only after it has been ascertained that the mistletoe is present, and that mistletoe-infected trees are not needed for wildlife considerations.

Dwarf mistletoes are native plants and have their niche in the ecosystem. As a native plant, they cannot be eradicated or completely removed but can be managed to maintain within NRV ranges in stands that are both productive and resilient. Tinnin *et al* (1982) list the fungi, arthropods, birds and mammals that use dwarf mistletoe brooms (of all species) for food, cover, or nesting. They cite at least 11 birds and 8 mammals. Stevens and Hawksworth (1970) made a first attempt to document insects and mites associated with dwarf mistletoes. There may be projects where mistletoe brooms are conserved for wildlife reasons. When reviewing an ecological restoration strategy for managing southwestern dwarf mistletoe in ponderosa, Wasserman and Waltz (2018) concluded that the current distribution of mistletoe is relatively similar to distribution 150 years ago. However, historical grazing practices and fire exclusion have allowed the ingrowth of smaller trees; and with the increase of trees on the landscape, the abundance of mistletoes may well now be higher than it was in the 1800's. Although they were not discussing NRV *per se*, their work in ponderosa replicates the findings in red fir, of Meyer and North (2019). The reintroduction of fire will kill many small firs and remove the cause of increased lateral spread of mistletoe. Reintroducing fire would reduce the abundance but not the distribution of dwarf mistletoe on the landscape and not adversely impact the brooms on which wildlife depend. Some trees with lower crown brooms may have to be either felled or pruned to ensure that reintroduced ground fires do not become crown-fires.

Both Wagener (1925) and Meinecke (1912) studied the incense cedar leafless, leafy mistletoe *Phoradendron junipeinum*. They conducted their work on Stanislaus National Forest in the vicinity of Cow Creek. They documented that the mistletoe could go totally systemic, and that systemic mistletoe could survive for over 400 years inside the host tree. Since then, the longevity of fir systemic infections of dwarf mistletoes has been well documented. Frequently the dwarf mistletoe plants get established by growing through the thin bark on a lateral branch close to the main stem (see Image 3). It is usual for the mistletoe seeds to become established at a time

when the branch has live or declining needles on it. If the point of the initial infection is close to the main stem the endophytic system (i.e. the absorbing roots) of the mistletoe can grow systemically down the branch and enter the main stem. Once the main stem bark thickens and grows over the infection the parasite becomes fully systemic (see Image 2). After any dwarf mistletoe seed germinates and grows into the host branch, it may be 2 to 6 years before the first aerial shoots appear on the branch (Wagener, 1962). Scharpf and Parmeter (1982) reported that rarely artificial inoculations with mistletoe seeds, that the delay between seed germination and the appearance of green aerial shoots, could take up to 10 years. During this latent period the plant is unable to photosynthesis and thus lives as an obligate internal parasite, this is the systemic phase of the endophytic system. Should the bark integrity become compromised these systemic infections can become invaded by decay fungi and these trees can become hazard trees in a recreational setting or wildlife trees in the general forest. However, FHP has observed many more examples of intact bole swellings, than examples of failures at the swelling. Parmeter and Scharpf (1982) concluded that:

"*…the dwarf mistletoe endophytic system in stem infections dies only when the host dies, the age of individual mistletoes in stems is limited only by the age of the tree*. "

Image 2. Bole swelling caused by a systemic infection of dwarf mistletoe infection of red fir. Bole infection is situated where a whorl of branches once was, for the infection begins in a thin barked branch close to the main stem where the endophytic system grows from into the main stem before being enclosed by the bark.

In an earlier paper Scharpf and Parmeter (1982) note that that mistletoe infected branches on true fir appear to die young, and thus the dwarf mistletoes may have a short average lifespan. Further they note that the death of these branches in effect slows the rate of the of mistletoe population build up. In radio tracer studies with $C^{14}O_2$ Hull and Leonard (1964) were able to show that the endophytic system of dwarf mistletoes accumulates nutrients stolen from the host plant. In general, the swelling induced by the mistletoe becomes a nutrient sink. These sinks contain higher levels of nutrition than the branch either side of the swelling. As such, they are attractive to insect or pathogens that have the ability to attack similar sized branches. Struble (1957) noted that *Scolytus subscaber* prefers gnarly or mistletoe infected branches in which to establish broods. Wright (1938) points out that *S. subscaber* carries a fungus *Spicaria anomala*, which would presumably help overcome the defenses of both host and roots of mistletoe plants. When rearing from dwarf mistletoe swelling of grey pine (MacKenzie *unpublished*) has frequently recovered the pine reproduction weevil, *Cylindrocopturus eatoni*, and occasionally the same host has yielded California flat headed borer (*Phaenops califonica)*. The timber stain fungus *Hormiscium gelatinosum* is invariably associated with the pine reproduction weevil (Eaton 1942). The preceding listings of insects and fungi was made to support the contention that dwarf mistletoes plants do not have a short life span; they are killed prematurely by organisms that preferentially attack the nutrient sinks that are the mistletoe swellings. This flagging of mistletoe infected branches in otherwise healthy trees is not reported for other mistletoe host combinations and is thus unique to the true firs.

While it has been speculated that insects may sometimes play a role in the flagging of mistletoe infected branches of true fir, evidence supports the conclusion that the major cause of flagged branches is the weak pathogen *Cytospora abietis* (Scharpf 1967, Parmeter & Scharpf 1982, & Wood *et al* 2003). Although *Cytospora abietis* is a common pathogen it is usually considered secondary as it only attacks trees that have been weakened by other agents such as, insects, other diseases, fire, drought, human activities, or mistletoes (Wood *et al* 2003). By stealing water and nutrient from its host tree, dwarf mistletoe stresses parts of a tree, i.e. the branches, which *Cytospora* then infects. The fungus usually kills no more than the mistletoe infected branch. Wright (1942) has shown that it can take 12 to 15 months for the fungus to completely girdle a half inch diameter branch. Scharpf and Bynum (1975) report that *Cytospora* can kill a branch in a little as six months or up to 2 years. In spring and summer during rainy periods, the fungus produces fruiting bodies in the patches of dead bark associated with the girdling cankers it causes. When it is wet, the fruiting bodies produce "spore horns" that appear as yellow curly threads of spores arising out of the fruiting bodies in the bark. It is assumed that the fungus is rain splash dispersed. In 1966, parts of California experienced a 9-month drought and the fungus was blamed for directly killing drought stressed firs (CA Pest Action Council 1966). The more common killing of individual branches gives tree crowns a ragged appearance (Hawksworth & Wiens 1996). Although Ferrell (1980) did not use a mistletoe rating *per se* when designing his risk rating system for red fir, his "percent crown raggedness" was an estimate mistletoe infection as indicated by *Cytospora* killed branches (see Image 3). And thus, Hawksworth DMR and Ferrell's risk rating systems have much in common and complement each other.

In one of the earliest studies of *Cytospora* and dwarf mistletoes Scharpf (1969) found that only 4% of branches not infected with mistletoe yielded the fungus, but 23% of mistletoe infected branches from Eldorado and Stanislaus National Forests yielded the fungus. Overall the fungus was recovered from 21% of living mistletoe-infected white fir branches, 25% of partially dead mistletoe branches, and 33% of dead mistletoe infected branches. This pathogen has the strong ability to act as a saprophyte. Because only 23% of the mistletoe infected branches were also *Cytospora* infected, it is not likely that *Cytospora* could be expected to eliminate the dwarf mistletoe. However, it is likely to act as a biological control agent and keep levels of mistletoe infection within their NRV.

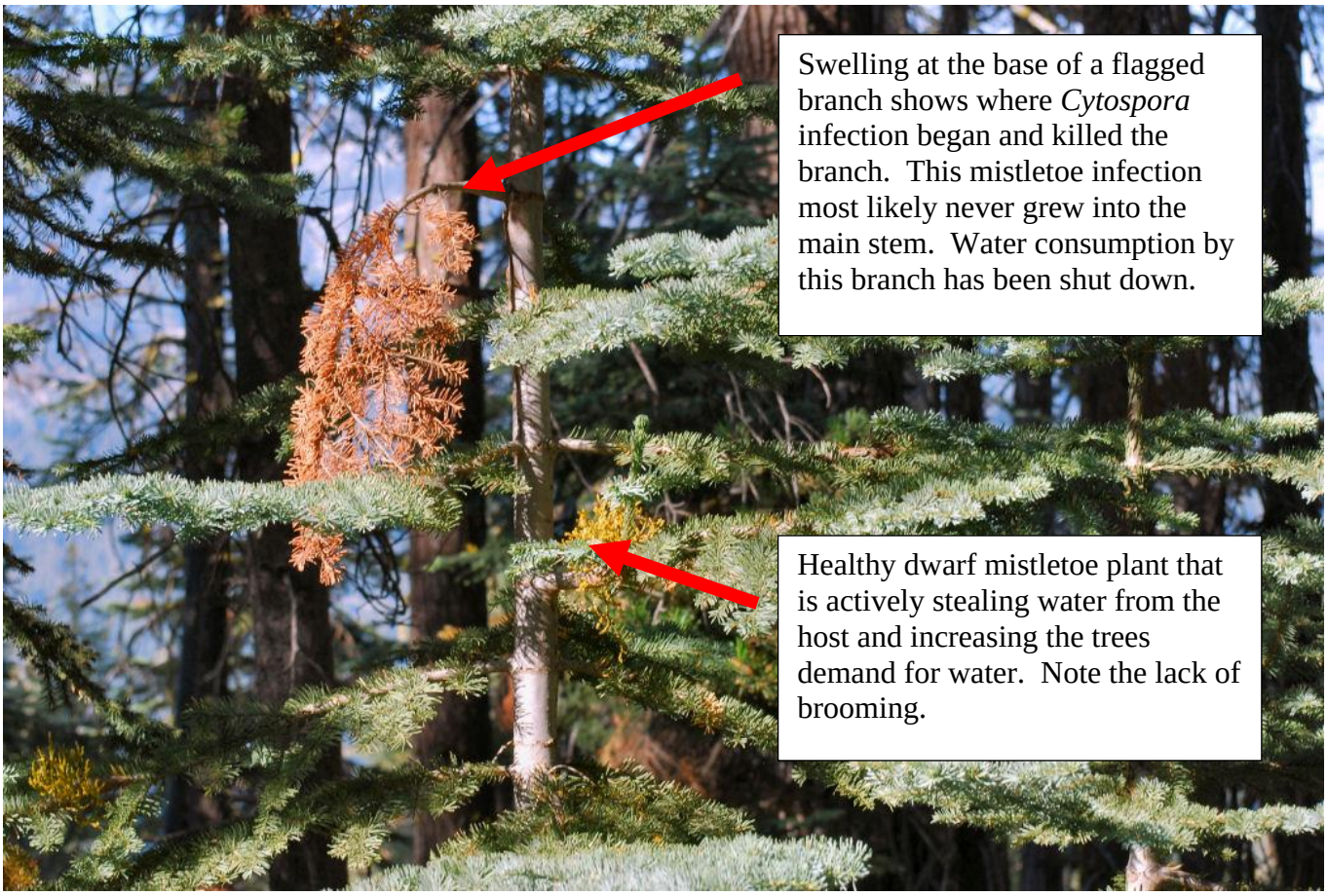

Swelling at the base of a flagged branch shows where *Cytospora* infection began and killed the branch. This mistletoe infection most likely never grew into the main stem. Water consumption by this branch has been shut down.
Healthy dwarf mistletoe plant that is actively stealing water from the host and increasing the trees demand for water. Note the lack of brooming.

Image 3. A small true fir to show the double-edged nature of dwarf mistletoe impacting water demand which becomes critical during a local drought.

Both Ferrell (1980, & 1989) and Hawksworth and Wiens (1996) stress the significance of the raggedness of a trees crown that a persistent level of mistletoe infection can eventually create in true firs. In their thinning recommendations Filip *et al* (2000) placed primary emphasis upon the live crown ratio of mistletoe infected trees, thereby combining the two rating systems. Rated by Ferrell (1989) system, the infected tree in Image 4 would have a high probability of dying in the next 10 years.

The dwarf mistletoe is another successful parasite that kills its host in the later stage of the infection, after the host has been weakened by other agents such as fire, insects, diseases, or competition with other trees. The fungus, *Cytospora abietis*, considered a weak pathogen, but also a successful pathogen, only kills its host after other agents have contributed to the trees demise. While *Heterobasidion occidentale*, *Scolytis ventralis, Arceuthobium abientinum* and *Cytospora abietis* may be considered primary agents for tree mortality, they rarely act alone. Other biotic and abiotic agents usually contribute to the eventual death of the host. In contrast, invasives such as WPBR, Emerald Ash borer, SOD or Goldspotted Oak borer, these don't require the assistance of prior biotic and abiotic injury to successfully kill hosts.

Image 4. A mature red fir, showing a ragged crown, due presumably to past *Cytospora* killing of earlier mistletoe infected branches.

Long-term effects of Dwarf Mistletoe

Most of large unmanaged red fir forests in the Sierra Nevada are mostly within their NRV (Meyer and North 2019). In recent decades though, there has been lengthening between fire return intervals and an intensification of mistletoe infection in saplings and pole-sized trees. If strategies are developed to reduce the levels of hazardous fuels and improve forest health, dwarf mistletoe mitigation should be considered. When individual projects are surveyed, dwarf mistletoe infection levels (stand or individual) should be assessed to determine if DM levels are outside of conditions that would sustain healthy forests. Economically viable strategies can be developed to bring down high mistletoe levels while not adversely impacting wildlife that depend upon mistletoe brooms. Some project specific strategies are discussed in the appendix B.

***Armillaria sp.* root rot**

One final pathogen to be mentioned regarding damaging biotic agents on true firs is *Armillaria* species. All though there are nine different species of *Armillaria* in North America (Baumgartener & Rizzo, 2001) none in California can rival the pathogenicity of *Armillaria ostoyae* to Douglas-fir and grand fir, in Idaho. (Hagle *et al,* 2003). (Note *Armillaria ostoyae* should now be called *Armillaria solidipes* (Burdsall &Volk, 2008). In the early days of molecular taxonomy, various isolates of *Armillaria* were classified by using North American Biological Species (NABS I-X) concept (Watling *et al* 1991). The isolates that were the last to be assigned to a morphological species were those of NABS X, which was recently described as *Armillaria altimontana* (Brazee *et al,* 2012). Recent research into *A. altimontana* Warwell *et al* (2019) discovered that this fungus might well turn out to be a potential biological control agent for the highly pathogenic *A. solidipes*, at least in western white pine (*P. monticola*) stands. When Baumgartner and Rizzo (2001) surveyed for *Armillaria* species in California, they essentially found *A. altimontana* to be restricted to Southern Cascades and northeastern corner of California. They found this species to be restricted to higher elevation white fir and red fir habitat types. However, the isolation of pathogenic *Armillaria* from red fir trees has been exceedingly rare (N. Klopfenstein, *personal communication*). FHP will be conducting surveys of cut stumps and collecting isolates of *Armillaria* species for further genetic analysis.

Armillaria recommendation

Although species of *Armillaria* present in states like Idaho, Oregon, and Washington are known to be particularly virulent, species found within the red fir forests of southern Sierras do not appear to pose a serious threat to the management of red fir. The disease is native to California and most of the concern would be in the lower hardwood forests or highly irrigated orchards (CA Forest Insect and Disease Training Manual). For this reason, no suppressive treatments appear necessary and further monitoring impacts of this disease would be prudent. If monitoring indicate that the disease is expanding or becoming a serious concern, FHP will assist in developing strategies for its control.

Insect complexes

Several insects have been identified in true firs in the Sierra Nevada, most of which work as involuntary mutual associates of each other but all working towards similar goals: survive, reproduce, and develop successful brood, all of which may require killing the host. Insects attracted to true firs often attack in "complexes" that invade different sections of the host, spatially and temporally. As differing sections of trees decline or are injured, a complex of insects utilize these opportunities to attack (aka niche partitioning). Attacks can be, localized at small injuries (ex: frost cracks, broken branch, etc.), recognized as dead branch flags or terminal-dieback. Fir engraver is typically considered main damage agent for true firs, preferring to attack injured, over-mature, drought-stressed, insect-defoliated, or diseased trees (Goheen and Hansen 1993). However, there is a large complement of other insects that also occur before or after initial attack, or where the opportunity arises on the host (Struble 1957). Healthy trees are often able to pitch out beetles and develop callus tissue over attack sites (Berryman 1969) but repeated attacks are good indicators that hosts are already in poor health (Ferrell 1973). In a study of a single white fir in Pinecrest Recreation Area on Stanislaus National Forest, Struble (1957) documented that it had been attacked by fir engraver on 7 separate occasions between 1888 and 1929. Trees with root disease infection keep hosts chronically stressed and can be detected among healthier individuals (Goheen and Hansen 1993, Ferrell and Smith 1976). Up to 40% of green trees found with some FE attack were infected by root disease (Cobb et al 1974), while white fir trees with true mistletoe (*Phoradendron pauciflorum*) infection were often selected, particularly during drought (Felix et al 1971).

Woodborers (Order Coleoptera, Family Cerambycidae and Buprestidae) and ambrosia beetles (Family Curculionidae and Platypodidae) are often in the lower bole when trees are attacked higher up by FE, while other *Scolytus* species will attack smaller diameter sections. *Scolytus subscaber* even prefers dwarf mistletoe affected wood, mostly confined to branches or terminals (Struble 1957). Insects have been found in variable

sections of autopsied trees, most perfectly partitioned to acquire optimal resource utilization in their distinctive spaces (Struble 1957). Other than fir engraver, many of these insects are not considered serious damage agents. However, the combination and cumulative of their damage contribute to overall host decline, eventually leading to death.

Forest variables that assess potential insect risk has been well researched, with likelihood for occurrence if certain thresholds are crossed, erupting into outbreaks (Raffa et al 2008). High basal areas and density have found to be universal stand conditions that are associated with high beetle risk for true fir ecosystems (Oliver and Uzoh1997, Ferrell et al 1994, Egan et al 2010). These confining forest conditions, in addition to recurring drought are known to trigger bark beetle outbreaks (Fettig 2012). Drought events benefit insects and pathogens as low water availability severely weaken hosts, making them less likely to repel or resist attacking pests. Drought, additional injuries, and crowded stand conditions exacerbate trees already under severe stress, thus increasing susceptibility to attack. Tree mortality associated with FE (and other agents) has been positively correlated with consecutive drought events in California (Felix et al 1971, Oblinger et al 2011), and is expected to exceed NRV if climatic water deficits continue in the coming decades (Meyer and North 2019).

Forest Health Monitoring (USDA Forest Service, Region 5) Aerial Detection Surveys from 2014-2018 noted delay in true fir mortality associated with the recent drought (see Appendix D). While lower elevation pines were rapidly dying in the early stages of the event, true fir mortality did not surge until the later stages. Mortality assessments ranged from light (4-10%) to moderate (11-25%) over large areas starting in 2014 and peaking in 2017. Ground surveys also find additional mortality of saplings and intermediate firs in the understory that is overlooked from the air, so actual mortality is often underestimated. Cumulative mortality due this recent drought may or may not be significant enough necessitate sweeping actions to restore these ecosystems, but an FHP assessment is planned to acquire an updated picture of current conditions in the proposed areas. Potential insect risk should be assessed in addition to fire/fuel modeling or expected vegetational changes when developing desired conditions to better visualize all outcomes of possible changes on the landscape. FHP can provide information and assistance with risk and modeling assessments.

Summary

These biotic agents can vary depending upon many variables of the environment, and management will be based on the objectives of site. Attached are appendixes (Appendix A through D) which summarize management recommendations for these agents, but also provide suggestions for overall benefit. Forest Health Protection will happily provide documentation, training, and further assistance if requested. If you have any questions regarding this report or need additional information, please contact Martin MacKenzie at (209) 288 6348 or Beverly Bulaon at (209) 288 6347.

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Appendix A. Management Recommendations for Use of Borate compound in True Firs

USDA Forest Service Regional Office (R5) guidelines for controlling the level of *Heterobasidion* Root Disease were drawn up after consulting extensive literature and forest pathologists of California (USFS and CalFire). These guidelines represent current known status and consensus of management for this disease. FHP is supports adoption of these guidelines for projects in most, if not all, red fir stands. While current red fir stands are largely within their NRV, some white fir stands that have experienced multiple entries (without borate application) have higher than normal levels of fir annosus that would be considered detrimental. Use of an approved borate stump dressing is the best way to ensure that fir annosus in red fir remains at background levels. The guidelines can be found in the links provided below.

Mitigation methods are described in the R05 Heterobasidion root disease web page at:
http://www.fs.usda.gov/detail/r5/forest-grasslandhealth/insects-diseases/?cid=stelprdb5329386.

Region 5 Policy is described in the FS Handbook 3409.11 at:
https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5329399.pdf

The Regional web pages provide links to commonly asked questions about treatments. These answers have been used to successfully answer the public concerns on many projects. FHP is available to find answers to other questions and provide training in the application of these preventative treatments. USDA Forest Service Handbook (USDA, 2013) maintains that stump surfaces are susceptible to infection by annosus for 2 to 4 weeks after they are cut. Cannon *et al* (2016) state the window is up to 4 days. However, labels of the only two products currently registered for use in California are Cellu-treat™ (manufactured by Nisus Corporation) or Sporax™ (by Wilbur-Ellis), have much narrower windows. For most efficient use Sporax™ should be applied immediately after cutting, and not later than 24 hours after cutting. Whereas Cellu-Treat™, which is also most effective immediately after cutting, can be applied up to 3 days after cutting. These are the windows of application that FHP is also recommending. Although Sporax™ is no longer in production it is still legal to use existing supplies of this chemical in California.

Appendix B. Management recommendations for Dwarf Mistletoe

While dwarf mistletoe (*Arceuthobium abietinum* f. sp. *magnificae*) is a serious pest of mature red fir trees, no action can be viable option if project activities include keeping dwarf mistletoe levels at manageable levels while reducing the fuels loading and increasing overall stand resiliency.

In such areas, the next rotation of red fir seedlings, saplings and poles, growing within drip line (or within twice the radius of the dripline) of large, overstory, heavily infected trees, should be the primary concern when deciding treatment options. This next generation of trees can become very heavily infested with mistletoes, thereby the focus should be on them and not the legacy trees. Almost all options will involve removal of some heavily infected seedlings, saplings, or poles. The goal should be to prevent lateral spread of the mistletoe, not eliminate it. In some projects, prescribed fires will sufficiently stop the lateral spread of mistletoe infections over large areas. Smaller scale treatments would be subsequent restoration of the *micro site* (a circle equal to twice the dripline radius of the heavily infested legacy trees). Some options for replacing heavily infested smaller trees are listed below. A project could include a number of these options, or combination.

1. After cutting, piling, and burning infested small trees, some sites could be left to naturally regenerate.
2. After cutting piling and burning the infested small trees, tractors could be brought in to scarify the micro site back to mineral soil, to provide an environment more suitable for the establishment of natural regeneration.
3. After clearing the micro site, with or without site prep, it could be hand planted with local red fir seedlings.
4. After clearing the micro site, with or without site prep, it could be hand planted with seedlings of other species that have a minor presence in the overall site. This would be done only to enhance bio-diversity and no attempt at overall species conversion would ever be attempted.
5. After clearing the micro site, with or without site prep, a small percentage of sites could be established with seedlings from seed sources originating from lower elevations. This would be done in an attempt to evaluate the assisted migration of seed sources of red fir or other species. Other species could be sugar, western white, lodgepole, or Jeffrey pines depending upon elevation.

Four major options are suggested to dealing with heavily dwarf mistletoe infested (legacy) trees at the center of micro-sites. FHP would anticipate that projects would incorporate a mix of at least two options.

- A significant number of large wolf trees can be left to preserve wildlife habitat. Such trees have significant value and wildlife biologists will be asked to provide guidelines on the number of such trees to retain. Mistletoe infested trees have a role to play in the ecosystem and FH objective of every project should be to improve the overall health of the stand. *Eliminating all heavily infested trees would not improve the overall forest health*.
- Any large wolf tree that threatens a road, trail, or structure will be felled.
- Wildlife guidelines used to determine how many wolf and/or heavily mistletoe infested trees left to complement the number of snags in the project.
- Once guidelines for the desirable number of snags have been determined, some heavily infested wolf trees can be either gridled or cut down. While a girdled tree will become a snag, the mistletoes dies that it is no longer an inoculum source.

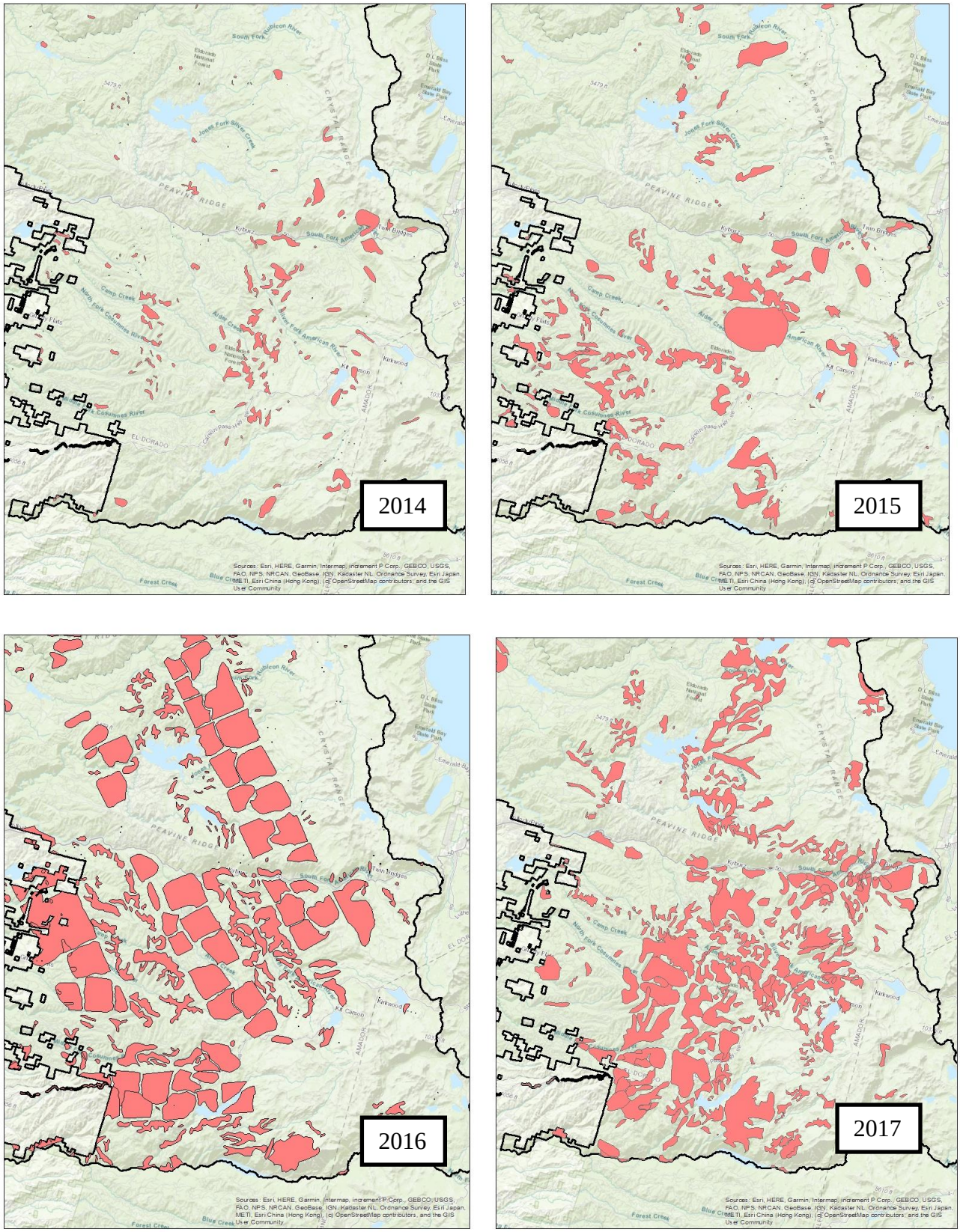
Appendix C. Management Recommendations for Integrated Pest Management in True fir stands

Since majority of endemic fir engraver populations are associated with root diseases, management of disease pockets will also serve to manage the fir engraver. *Silvicultural practices aimed at maintaining healthy stand conditions appear to offer the best chance for minimizing engraver-caused mortality.* Stand thinning measures for fir stands on drier sites generally do not seem to yield the same benefits that are seen with pines. However, thinning does typically result in increased growth and vigor and in wetter areas (areas with annual precipitation greater than >35"). Care should be taken during treatments to minimized tree injury and compaction as residual firs are easily damaged during harvest activities and are sensitive to soil compaction. These additional stresses can make them even more susceptible to fir engraver attacks after treatment than before. Large-scale outbreaks associated with drought conditions can best be managed by reducing the occurrence of the fir host on dry sites. Once an outbreak begins, sanitation/salvage appears to result in little or no population reduction of fir engravers. (CA Insect and Disease Training Manual 2014)

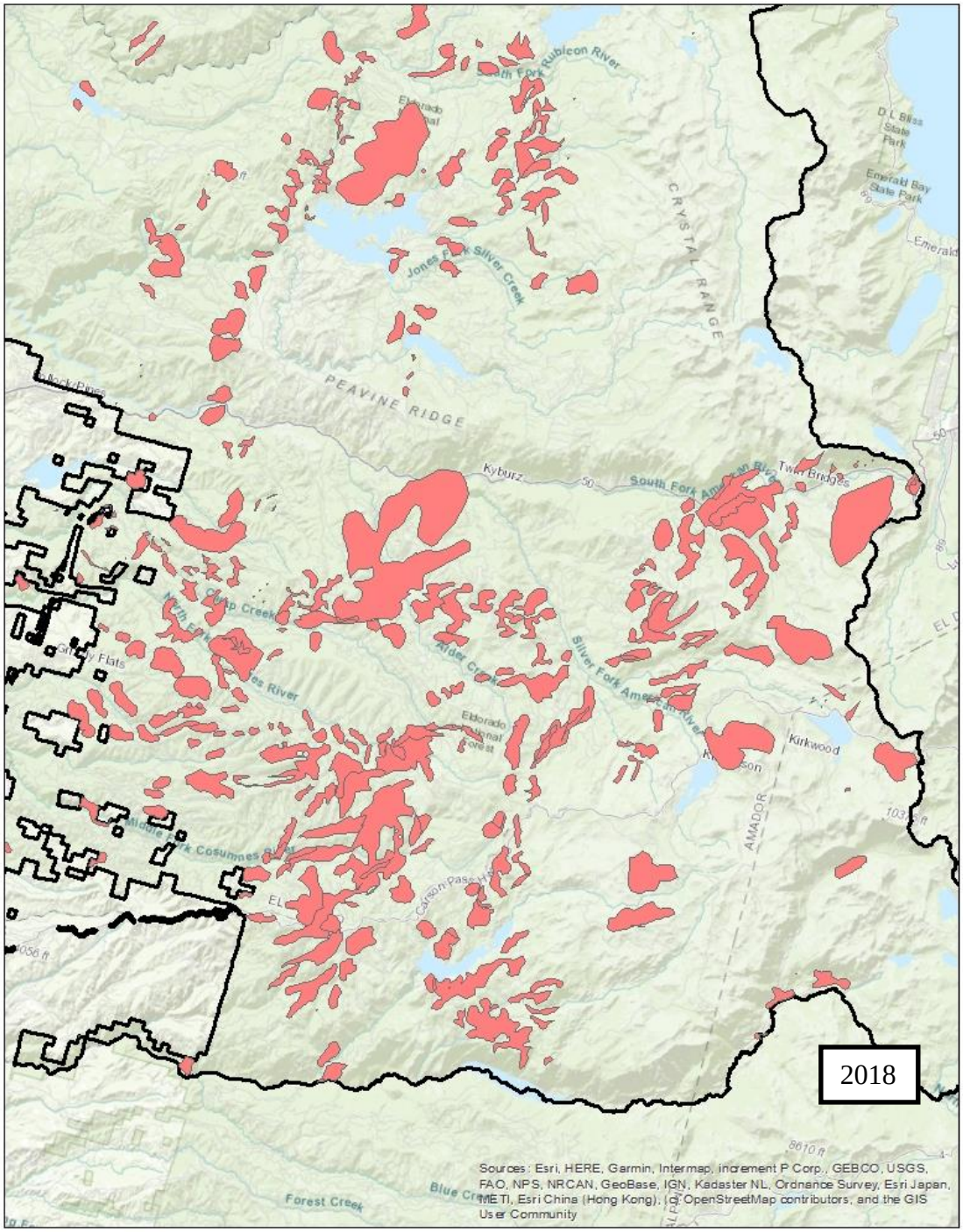
Summarized recommendations for treatment in true fir stands:

- Select against trees with fair to poor vigor based on crown or bole conditions, or level of DM infections (Ferrell 1989, Hawksworth DM rating 1977). Suppressed and intermediate (crown position) growing trees are at highest risk for continual attack (Ferrell 1973).
- Encouraging diversity of other species (ex: pines, brush) in stands by reducing proportion of host type available
- If root disease presence is confirmed, consider creating large openings to disrupt root-to-root connections, remove potentially infected and infected hosts. Planting non-hosts or allowing gap openings should reduce disease persistence.
- Removal of additional hosts are the margins of identified root disease pockets should reduce disease expansion while providing buffer.
- Reducing basal area or stocking to more optimal conditions for the site. Reducing resource competition and creating desirable conditions that promote vigor and productivity significantly reduce attractiveness to insect infestation. Mitigating factors that predispose hosts to insect attack also increase tree resiliency and resistance to other damaging agents or disturbances.

Appendix D. FHM Aerial Detection Surveys (2014, 2015, 2016, 2017 respectively) of SoFar Red Fir Strategy Proposed Area. ***Note: Polygons identify all areas detected with some fir engraver-associated mortality. .***



Appendix D (continued). FHM Aerial Detection Surveys 2018 of SoFar Red Fir Strategy Proposed Area
Note: Polygons identify all areas detected with some fir engraver-associated mortality


South Fork Rubicon River
D L Bliss State Park
Emerald Bay State Park
CRYSTAL RANGE
Jones Fork Silver Creek
PEAVINE RIDGE
Kyburz
South Fork American River
Twin Bridges
Silver Fork American River
Kirkwood
AMADOR
Forest Creek
2018
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community